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Analyzing Long-Term Trends in Air Temperature and Precipitation in Bel-Ksiri, Morocco (1980–2024)

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The study analyzes climate change in Bel-Ksiri. It provides an understanding of long-term trends (1980-2024) and changes between the last two standard twenty-year climate periods: 1980-2000 and 2001-2020.In this study, we determined the trend of the two variables studied using the Mann-Kendall test and calculated the difference and relative variations in temperature and precipitation. The Kolmogorov-Smirnov test (KS test) was used to compare the two climate periods studied (1980-2000 and 2001-2020). Data analysis was performed using the Python language. Climate trends from 1980 to 2024 reveal a marked warming, particularly in spring and summer, with an increase in daily temperature variations, exacerbating the risk of drought and impacting agriculture, water resources and health. The periods 1980-2000 and 2001-2020 show significant differences, notably an increase in maximum and minimum night-time temperatures, particularly during summer and spring. Analysis of climate indices, such as TX90p and TN90p, shows increases in temperature extremes, with notable rises in hot days and warm nights, underlining gradual warming. The TX30, TX35, TX37 and TX39 indices also show significant increases. Hot spells (WSDI) and cold spells (CSDI) have intensified, although some trends are not statistically significant. These results confirm a marked climate change, with significant impacts on ecosystems and human societies. Precipitation trends show overall rainfall stability, with a slight annual increase (+1.97%) and a notable fall decrease (-6.5%). At Bel-Ksiri, between 1980 and 2024, precipitation indices show small and insignificant variations, with slight increases in PRCPTOT (+1.09 mm/10 years) and RX1day (+0.09 mm/10 years). Analysis of rainy days reveals a slight decrease in days with ≥1 mm (-0.51%) and an increase in days with ≥10 mm (+9.82%), while dry and wet periods have changed slightly, with no statistically significant differences.
Keywords: Climate change, global warming, flood risks, water resources, ecosystem .

INTRODUCTION

Climate change is currently observed through two main indicators: precipitation and temperature. Climate forecasts based on the Trewartha climate classification system (TWCC) indicate an increase in global temperature in °C, as well as a change in precipitation amounts in mm (Valjarević *et al.*, 2022). These changes have had an impact on many countries around the world, such as Thailand, where increases in maximum, minimum and dune temperatures are predicted (Phumkokrux, 2023).

Global air temperature has been rising since the end of the 19th century, IPCC (2021). The IPCC's Sixth Assessment Report on Climate Change indicates that global average air temperature in 2001-2020 was almost 1°C higher than in the period 1850-1900, IPCC (2021). As a result, the impact of climate change has become the most accessible topic in the scientific community. On a global scale, the intensity of heat and cold extremes has changed considerably (Zhang *et al.*, 2022). Indices representing extreme air temperatures have shown almost generalized changes across the globe, consistent with global warming (Dunn *et al.*, 2020). All indicators of the lowest and highest absolute minimum and maximum temperatures followed an upward trend, with an

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increase of up to almost 4°C for TNn on a global scale (Dunn *et al.*, 2020). Global trends in temperature indices based on percentiles also confirm warming (Zhang *et al.*, 2019; Dunn and Morice, 2022): the frequency of cold nights and days has fallen sharply, while that of warm nights and days has risen sharply worldwide (Alexander, 2016). Moreover, the increase in the frequency of indices linked to minimum temperatures (TN90p, TN10p) is more marked than that of indices linked to maximum temperatures (TX90p, TX10p). What's more, the increase in hot days is far greater than the decrease in cool days, with an overall average difference of around 30 days versus 15 days since the 1970s (Dunn *et al.*, 2020). Temperature and precipitation trend studies show an increase in temperature and a decrease in precipitation (Hakam *et al.*, 2022; Jasman *et al.*, 2023). Studies conducted to detect temperature trends have recorded an increase of 0.5 to 1.2°C, whether natural or due to human intervention, which is having a negative impact on water resources from various sources such as flooding (Wilhelm *et al.*, 2022). In Africa, 2023 was one of the three hottest years in the last 124 years, regardless of the dataset used. The average temperature was 0.61°C above the average for the period 1991-2020 and 1.23°C above the value for the reference period, 1961-1990 (WMO, 2023). In Morocco, studies have highlighted that Morocco suffers from extreme thermal effects accentuated by the effects of climate change in terms of diversity, intensity and occurrence, notably heat waves and heat waves, both of which have been well and truly 35th Annual Colloquium of the International Association of Climatology - AIC 2022 observed frequently in recent decades and will persist for a long time with temperatures reaching the limits (Driouech *et al.*, 2013; Schilling *et al.*, 2020). Precipitation is a pivotal factor in the replenishment of global water resources, impacting river flow variability, flood risk, ecosystem health and water availability in watersheds (Abera *et al.*, 2017; Zhao *et al.*, 2015; Kliment *et al.*, 2011). Among the regions experiencing a significant rainfall deficit is the western part of North Africa, which has recorded precipitation levels below normal (WMO, 2023). Recent studies have highlighted an increase in extreme precipitation indices in North Africa. For example, an analysis carried out in northern Morocco over the period 1976-2016 revealed an upward trend in the RX1day (maximum rainfall in one day) index at certain coastal stations, notably Safi, Essaouira and Agadir. These stations recorded increases of between 5.86 mm and 6.89 mm. Similarly, stations in Al Hoceima, Tétouan, Chefchaouen and Ifrane recorded values ranging from 5.12 mm to 5.86 mm. By contrast, the RX5day index (maximum rainfall over five consecutive days) showed an upward trend at only three stations, with increases ranging from 3.81 mm to 7.19 mm (Bouaiche *et al.*, 2021). With regard to the R95p index (very abundant rainfall, above the 95th percentile), five stations showed a positive trend. The Agadir, Essaouira and Safi stations, located along the Atlantic coast, recorded increases of between 14.93 mm and 17.27 mm. The Al Hoceima and Tétouan stations, meanwhile, recorded increases of between 19.71 mm and 22.99 mm (Bouaiche *et al.*, 2021).

MATERIALS AND METHODS

This paper aims to analyze climate change in Bel-Ksiri, Morocco, over one period (1980-2024). The aim of this paper was to analyze trends in mean and extreme air temperatures and precipitation amounts at Bel-Ksiri in 1980-2024, and to study changes between the last two periods 1980-2000 and 2001-2020, using the Python programming language. The study area is located in the Gharb, which refers to the plain of the lower course of the Oued Sebou as well as its surrounding highlands. This plain offers a wide variety of landscapes. To the north, the high Gharb is a region of Miocene marl hills. To the east, it is clearly dominated by the pre-Rif folds of Jbel Outita. The boundary is less distinct to the south, where the plain dips under the sandy Villafranchian plateau of Mamora. Finally, to the west, a cordon of consolidated Quaternary dunes isolates it from the Atlantic Ocean (Le Coz, 1964).

Table 1. Characteristics of the input variables in Bel-Ksiri in 1980–2024.

Variable	Average	Maximum	Minimum	Standard deviation	Skewness	Kurtosis
Ta	19.26	40.15	3.7	5.82	0.24	-0.80
Tmax	25.07	50.10	8.2	7.06	0.35	-0.63
Tmin	13.44	31.40	-3.0	5.02	-0.005	-0.79
R	454.03	63.00	0.0	3.94	5.28	39.08

Table 2. Average values of the input variables in Bel-Ksiri in 1980–2024.

Variable	Year	Winter	Spring	Summer	Autumn
Ta	19.26	12.97	17.60	25.56	20.80
Tmax	25.08	17.83	23.46	32.51	26.36
Tmin	13.45	8.10	11.74	18.60	15.24
R	454.03	184.26	127.70	9.40	132.66

Climate change in the central plain between 1980 and 2024 was analyzed using daily climate data on air temperatures - mean, maximum and minimum (Ta, Tmax, Tmin) - and precipitation (R). The data come from the Bel-Ksiri meteorological station located at 34° 34' 59.44 “N and 5° 57' 36.40” W, with an altitude of 15 meters. The source of this data is NASA POWER. Table 1 presents descriptive statistics for four climatic variables: Ta (mean temperature), Tmax (maximum temperature), Tmin (minimum temperature) and R (precipitation). For each variable, the values are given as average, maximum, minimum, standard deviation, skewness and kurtosis. For example, for mean temperature (Ta), the mean is 19.26°C, the maximum temperature is 40.15°C, the minimum is 3.7°C, the standard deviation is 5.82, the skewness is 0.24 and the kurtosis is -0.8. For Tmax, the mean is 25.07°C with a maximum of 50.1°C and a minimum of 8.2°C. Precipitation (R) has a mean of 454.03 mm, with a maximum of 63 mm and a minimum of 0 mm, a high standard deviation of 3.94 and very marked asymmetry and kurtosis measurements (5.28 and 39.08 respectively).

Table 2 shows climate data for several seasons (winter, spring, summer, autumn) for various variables, including mean temperature (Ta), maximum temperature (Tmax), minimum temperature (Tmin) and precipitation (R). The values shown for each season are as follows:

- Mean temperature (Ta) values range from 12.97°C in spring to 25.56°C in summer.
- The maximum temperature (Tmax) ranges from 17.83°C in spring to 32.51°C in summer.
- Minimum temperature (Tmin) ranges from 8.10°C in spring to 18.60°C in autumn.
- Precipitation (R) peaks in winter (454.03 mm), with a significant fall in autumn (132.66 mm) and lower values in spring (184.26 mm) and summer (127.70 mm).

Based on the input data, 15 extreme air temperature indices and 10 extreme precipitation indices from ETCCDI, widely used in climate change studies, were calculated. The selected indices represent absolute values, percentiles, fixed thresholds, and duration-based indices. Their definitions, labels, and calculations follow the recommendations of ETCCDI (2009).

Additionally, four more temperature indices and one precipitation index based on fixed thresholds were included:

- Tropical days (TX30): Number of days per year with a maximum temperature ≥ 30°C
- Very hot days (TX35): Number of days per year with a maximum temperature ≥ 35°C
- Extreme hot days (TX37): Number of days per year with a maximum temperature ≥ 37°C
- very extreme hot days (TX39): annual count of days with maximum air temperature >= 39°C; and
- Wet days (R01mm): Number of days per year with precipitation ≥ 1 mm

Indices were calculated in xclim (Bourgault *et al.*, 2023). Indices’ average values in 1980−2024 are given in Tab. 3. But before that, it is necessary to explain the meanings of the indicators used in the study.

Temperature Indices:

- TXx: Highest recorded daily maximum temperature.
- TXn: Lowest recorded daily maximum temperature.
- TNx: Highest recorded daily minimum temperature.
- TNn: Lowest recorded daily minimum temperature.
- TX10p: Number of days when the maximum temperature is below the 10th percentile (cold days).
- TX90p: Number of days when the maximum temperature is above the 90th percentile (hot days).
- TN10p: Number of days when the minimum temperature is below the 10th percentile (cold nights).
- TN90p: Number of days when the minimum temperature is above the 90th percentile (warm nights).
- TR20: Number of days when the minimum temperature exceeds 20°C (tropical night).
- SU25: Number of days when the maximum temperature exceeds 25°C (summer day).
- TX30: Number of days when the maximum temperature exceeds 30°C.
- TX35: Number of days when the maximum temperature exceeds 35°C.
- TX37: Number of days when the maximum temperature exceeds 37°C.
- WSDI: Total number of days in heatwaves (at least 6 consecutive days with TX > 90th percentile).
- CSDI: Total number of days in cold spells (at least 6 consecutive days with TN < 10th percentile).
- FD0: Number of frost days (minimum temperature < 0°C).
- ID0: Number of days when the maximum temperature remains below 0°C.
- GSL: Growing season length (period between the first day of 5 consecutive days with T mean > 5°C and the last day before 5 consecutive days with T mean < 5°C).

Precipitation Indices:

- RX1day: Maximum daily precipitation.
- RX5day: Maximum precipitation over 5 consecutive days.
- R01mm: Number of days with precipitation ≥ 1 mm.
- R10mm: Number of days with precipitation ≥ 10 mm.
- R20mm: Number of days with precipitation ≥ 20 mm.
- R95p: Total precipitation exceeding the 95th percentile of wet days.
- R99p: Total precipitation exceeding the 99th percentile of wet days.
- PRCPTOT: Total annual precipitation.
- CWD: Maximum number of consecutive wet days (precipitation ≥ 1 mm).

- CDD: Maximum number of consecutive dry days (no precipitation).

Table 3. Average values of indices used for analysis in 1980–2024.

Index	Value	Index	Value
TXx	50.1 days	TN90p	1640.0 days
TXn	-3.0 days	WSDI	4368.0 days
TNx	50.1 days	CSDI	7.0 days
TNn	-3.0 days	R01mm	2722.0 days
TR20	11498.0 days	R10mm	644.0 days
SU25	7829.0 days	R20mm	156.0 days
RX1day	63.0 days	R95p	12805.8 days
RX5day	121.9 days	R99p	4495.0 days
TX30	4368.0 days	ID0	11924.0 days
TX35	1478.0 days	GSL	9630.0 days
TX37	857.0 days	FD0	7.0 days
TX10p	1629.0 days	PRCPTOT	20431.7 days
TX90p	1629.0 days	CWD	4513.0 days
TN10p	1577.0 days	CDD	7829.0 days

The nonparametric Mann-Kendall test was used to assess trend slopes and their statistical significance over the period 1980–2024, at both annual and seasonal levels. Additionally, changes between the two most recent 20-year climatological periods (1980–2000 and 2001–2020) were analyzed. This analysis included evaluating differences in average values between the two periods and examining distributional changes using the nonparametric Kolmogorov-Smirnov test.

RESULTS

***Changes in mean, maximum, and minimum air temperature*:** The climate trends in Table 4 over the period 1980-2024 show a significant warming of mean (Ta), maximum (Tmax) and minimum (Tmin) temperatures, with respective increases of +0.43°C, +0.57°C and +0.26°C per decade on an annual scale. Increases are particularly marked in spring (+0.63°C for Ta, +0.82°C for Tmax and +0.41°C for Tmin) and summer (+0.54°C for Ta, +0.83°C for Tmax and +0.27°C for Tmin), indicating early warming and intensification of summer heat waves. Autumn and winter show more moderate trends, although still significant, except for Tmin in autumn, where no clear evolution is observed.

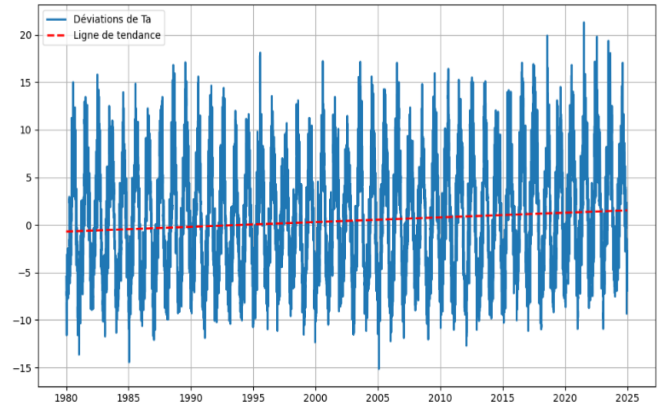

Figure 1. Deviations (in °C) of Ta from 1980–2000 averages (the dashed line represents the trendline).

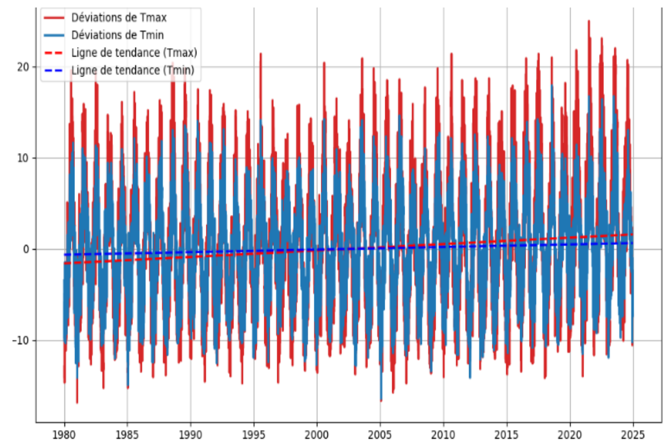

Figure 2. Deviations (in °C) of Tmax, and Tmin from 1980–2000 averages (the dashed line represents the trendline).

The differences observed in Table 5 between the periods 1980-2000 and 2001-2020 in mean (Ta), maximum (Tmax) and minimum (Tmin) temperatures reflect marked climate change trends, with notable increases in summer and spring temperatures. These temperature increases, particularly for Ta and Tmax, indicate sustained global warming, with significant differences between the two periods (up to 1.72°C in summer for Tmax), which is consistent with global warming trends. The results of the Kolmogorov-Smirnov tests reveal that the temperature distributions are statistically

Table 4. Trends in Ta, Tmax, and Tmin in Bel-Ksiri in 1980−2024 (in °C/10yr).

Index	Metric	Year	Winter	Spring	Summer	Autumn
Ta	Slope	0.4300	0.3600	0.6300	0.5400	0.3900
Ta	p-value	<0.0001	0.0029	<0.0001	<0.0001	0.0199
Tmax	Slope	0.5700	0.4400	0.8200	0.8300	0.5600
Tmax	p-value	<0.0001	0.0008	<0.0001	<0.0001	0.0058
Tmin	Slope	0.2600	0.2500	0.4100	0.2700	0.1700
Tmin	p-value	0.0003	0.0399	<0.0001	0.0042	0.1270

different between these two periods, reinforcing the idea of locally perceptible climate changes. Although the changes for Tmin are less pronounced, the differences remain significant for certain seasons, which could suggest a more pronounced warming of warm days and less cool nights, a phenomenon often observed in the context of climate change. These trends are characteristic of the effects of climate change, with potential impacts on ecosystems, water resources and human societies, particularly in regions sensitive to temperature variations.

Table 5. Difference in average values of Ta, Tmax, and Tmin in Bel-Ksiri in 2001–2020 in reference to 1980–2020.

	Ta			
	Winter	**Spring**	**Summer**	**Autumn**
1980–2000	12.65	16.97	24.85	20.38
2001–2020	12.91	17.95	25.98	20.92
Difference (°C)	0.25	0.98	1.134	0.54
Difference (%)	2.005	5.78	4.56	2.67
D [KS test]	0.05	0.10	0.13	0.08
p-value [KS test]	0.005	2.23	2.14	9.49
	Tmax			
1980–2000	17.35	22.62	31.43	25.73
2001–2020	17.84	23.91	33.15	26.55
Difference (°C)	0.48	1.29	1.72	0.81
Difference (%)	2.81	5.71	5.47	3.17
D [KS test]	0.07	0.12	0.15	0.09
p-value [KS test]	5.13	5.37	7.49	4.93
	Tmin			
1980–2000	7.95	11.33	18.27	15.02
2001–2020	7.97	12.003	18.8	15.30
Difference (°C)	0.01	0.67	0.54	0.27
Difference (%)	0.24	5.91	2.99	1.8
D [KS test]	0.02	0.09	0.08	0.06
p-value [KS test]	0.44	2.29	4.8	0.00

***Changes in extreme temperature indices*:** Table 6 shows trends in the TNn, TNx, TXn and TXx climate indices by season (autumn, spring, summer, winter) and on an annual scale. For TNn, the slope is 0.0245 with a p-value of 0.1459, indicating a positive but non-significant trend. For TNx, the slope is 0.0709 with a p-value of 0.0054, suggesting a significant increase. For TXn, the slope is 0.0473 with a p-value of 0.0043, also showing a significant increase. Finally, for TXx, the slope is 0.1090 with a p-value of 0.0002, indicating a highly significant increase. These trends are consistent across all seasons and throughout the whole year.

The data in Table 7 shows increase in maximum (TXx) and minimum (TNn) night-time temperatures for winter, spring and summer, while autumn shows a decrease in maximum (TXx) and minimum (TXn) temperatures. In winter, temperature differences ranged from 0.2°C to 2.7°C, with a 100% increase for TNn. Spring saw an increase of 3.9°C for TXx and a moderate rise for TXn and TNx.

Table 6. Trends in absolute air temperature indices in Bel-Ksiri in 1980−2024 (in °C/10yr).

Index		**Autumn**	**Spring**	**Summer**	**Winter**	**Year**
TNn	Slope	0.024	0.020	0.024	0.024	0.020
	P-value	0.140	0.140	0.145	0.145	0.140
TNx	Slope	0.070	0.070	0.070	0.070	0.070
	P-value	0.005	0.005	0.005	0.005	0.005
TXn	Slope	0.040	0.040	0.047	0.047	0.047
	P-value	0.004	0.004	0.004	0.004	0.004
TXx	Slope	0.100	0.100	0.109	0.100	0.100
	p-value	0.000	0.000	0.000	0.000	0.000

Table 7. Difference in average values of absolute values air temperature indices in Bel-Ksiri in 2001–2020 in reference to 1980–2000.

Index	**TXx**	**TXn**	**TNx**	**TNn**
Winter_Mean_1980_2000	27.00	8.20	16.80	-1.50
Winter_Mean_2001_2020	29.70	8.40	17.10	-3.00
Winter_Difference_C	2.70	0.20	0.30	-1.50
Winter_Difference_Percent	10.00	2.40	1.78	100.00
Winter_KS_D	0.08	0.04	0.08	0.04
Winter_KS_p_value	9.38	1.89	9.38	1.89
Spring_Mean_1980_2000	38.80	11.10	22.60	1.80
Spring_Mean_2001_2020	42.70	11.60	23.90	1.80
Spring_Difference_C	3.90	0.50	1.30	0.00
Spring_Difference_Percent	10.05	4.50	5.75	0.00
Spring_KS_D	0.08	0.04	0.08	0.04
Spring_KS_p_value	9.38	1.89	9.38	1.89
Summer_Mean_1980_2000	46.50	19.10	27.70	10.30
Summer_Mean_2001_2020	46.90	21.60	31.40	10.70
Summer_Difference_C	0.40	2.50	3.70	0.40
Summer_Difference_Percent	0.80	13.08	13.35	3.88
Summer_KS_D	0.08	0.04	0.08	0.04
Summer_KS_p_value	9.38	1.89	9.38	1.89
Autumn_Mean_1980_2000	44.00	12.60	25.60	2.50
Autumn_Mean_2001_2020	42.90	11.70	26.20	3.10
Autumn_Difference_C	-1.10	-0.90	0.60	0.60
Autumn_Difference_Percent	-2.50	-7.14	2.34	24.00
Autumn_KS_D	0.08	0.04	0.08	0.04
Autumn_KS_p_value	9.38	1.89	9.38	1.89

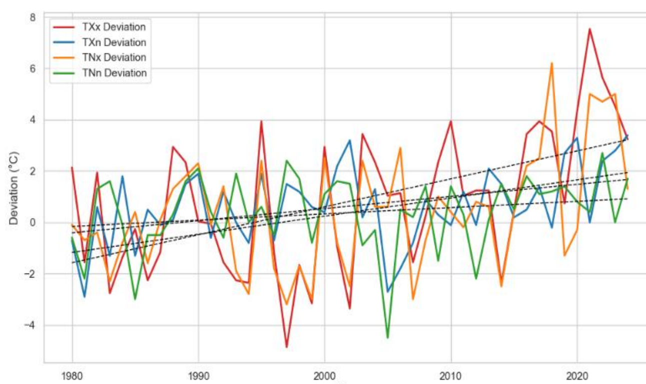

Figure 3. Deviations (in °C) of the selected absolute air temperature indices from 1980–2000 averages (the dashed line represents the trendline).

Summer saw a slight increase in maximum (0.4°C) and minimum night-time temperatures (0.4°C), while autumn saw a drop of 1.1°C for TXx and 0.9°C for TXn, but a slight increase of 0.6°C for TNx and TNn. KS tests show small differences (0.04 to 0.08), suggesting that temperature distributions did not change significantly between the periods 1980-2000 and 2001-2020, although mean variations were observed.

Table 8 shows the trends in percentile-based climate indices over the period 1980-2024. The results show a significant increase in the number of days on which TX90p is exceeded, particularly in spring (+1.43 days/10 years, $p < 0.0001$) and summer (+1.12 days/10 years, $p < 0.0001$). In contrast, TN10p, an indicator of cold nights, shows a slight increase in winter and spring (+0.26 days/10 years) but remains stable in autumn ($p = 0.89$), suggesting a greater reduction in extreme cold temperatures during the warmer seasons.

Finally, Figures 4 and 5 illustrate the deviations of percentile-based temperature indices from the 1980-2000 mean. The dotted line representing the trend indicates a progressive increase in extreme hot temperatures and a decrease in extreme cold, corroborating the results of the tables. These trends confirm the amplification of global warming in the Gharb plain and underline the importance of continuous monitoring of thermal extremes.

Table 8. Trends in percentile-based air temperature indices in BEL-Ksiri in 1980−2024 (in days/10yr).

Index	Season	Slope	p-value
TN10p	Winter	0.26	0.03
TN10p	Spring	0.26	0.01
TN10p	Summer	0.21	0.04
TN10p	Autumn	0.02	0.80
TX10p	Winter	0.36	0.00
TX10p	Spring	0.34	0.01
TX10p	Summer	0.70	<0.0001
TX10p	Autumn	0.41	0.06
TN90p	Winter	0.18	0.20
TN90p	Spring	0.52	<0.0001
TN90p	Summer	0.26	0.02
TN90p	Autumn	0.01	0.90
TX90p	Winter	0.63	0.001
TX90p	Spring	1.43	<0.0001
TX90p	Summer	1.12	<0.0001
TX90p	Autumn	0.33	0.226918

Analysis of the climate indices in Table 9 shows a general increase in temperature extremes between 1980-2000 and 2001-2020. For TX10p (cold days), variations are small in winter (+0.4 days, +2.83%) and spring (+0.09 days, +0.51%), while summer sees a more marked increase (+1.99 days, +7.68%). TX90p (warm days) increases in all seasons, particularly in spring (+2.71 days, +9.57%) and summer (+2.2 days, +5.85%). TN10p (cold nights) shows modest increases except in autumn (-0.1 days, -1.01%). In contrast, TN90p (warm nights) increases strongly in spring (+1.3 days, +8.67%) and summer (+0.6 days, +2.79%). The Kolmogorov-Smirnov (KS) test indicates statistically significant differences for several indices, notably TX90p Spring ($p = 5.36$) and TN90p Spring ($p < 0.001$), underlining a notable change in climatic distributions over the two periods.

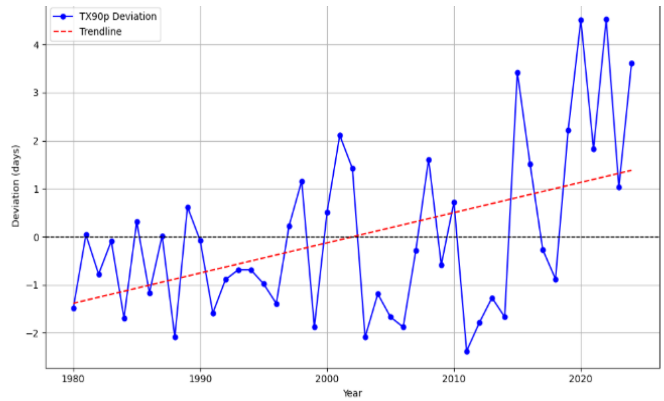

Figure 4. Deviations (in days) of the selected percentile-based air temperature indices from 1980–2000 averages (the dashed line represents the trendline).

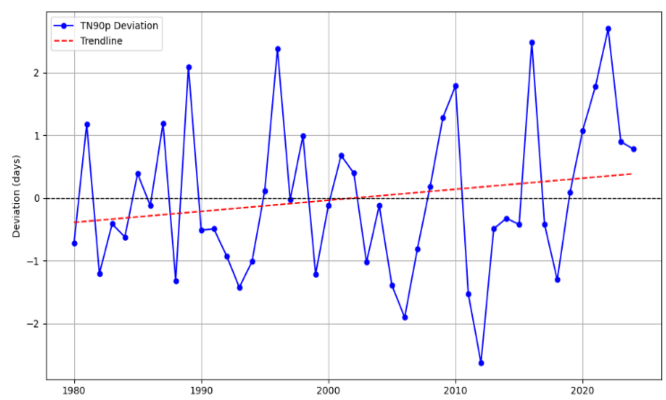

Figure 5. Deviations (in days) of the selected percentile-based air temperature indices from 1980-2010 averages (the dashed line represents the trendline).

Table 10 shows the trends of various climatic indices with their slope and p-value. The ID0 and FD0 indices show a zero slope with a p-value of 1, indicating the absence of a significant trend. In contrast, the TR20, SU25, TX30, TX35, TX37 and TX39 indices show positive slopes, suggesting an increase over time. The TX30 index shows the highest increase (1.336232) with very high significance ($p = 8.04$), followed by SU25 (1.09, $p = 1.44$) and TR20 (1.06, $p = 5.21$). TX35, TX37 and TX39 also show significant trends, with respective slopes of 0.77 ($p = 4.92$), 0.5 ($p = 0.00$) and 0.37

Table 9. Difference in average values of percentile-based air temperature indices in Bel-Ksiri in 2000–2020 in reference to 1980–2000.

Index	Saison	1980-2000	2001-2020	Difference (days)	Difference (%)	D [KS test]	p-value [KS test]
TX10p	Winter	14.10	14.50	0.40	2.83	-0.40	5.125
TX10p	Spring	17.50	17.59	0.09	0.51	-0.09	5.36
TX10p	Summer	25.91	27.90	1.99	7.68	-1.99	7.48
TX10p	Autumn	18.50	18.80	0.30	1.62	-0.30	4.92
TX90p	Winter	21.00	21.76	0.76	3.61	-0.76	5.12
TX90p	Spring	28.29	31.00	2.71	9.57	-2.71	5.36
TX90p	Summer	37.60	39.80	2.20	5.85	-2.20	7.48
TX90p	Autumn	32.90	33.90	1.00	3.03	-1.00	4.92
TN10p	Winter	4.40	4.50	0.10	2.27	-0.10	0.44
TN10p	Spring	7.60	7.90	0.30	3.94	-0.30	2.29
TN10p	Summer	14.90	15.50	0.60	4.02	-0.60	4.79
TN10p	Autumn	9.90	9.80	-0.10	-1.01	0.10	0.00
TN90p	Winter	11.50	11.50	0.00	0.00	0.00	0.44
TN90p	Spring	15.00	16.30	1.30	8.66	-1.30	2.29
TN90p	Summer	21.50	22.10	0.60	2.79	-0.60	4.79
TN90p	Autumn	19.90	19.90	0.00	0.00	0.00	0.00

(p = 7.56), indicating a gradual increase in extreme temperatures.

Table 10. Trends in annual fixed threshold air temperature indices in Bel-Ksiri in 1980−2024 (in days/10yr).

Index	Slope	p-value
ID0	0.00	1.00
FD0	0.00	1.00
TR20	1.06	5.21
SU25	1.09	1.44
TX30	1.33	8.04
TX35	0.77	4.92
TX37	0.50	0.00
TX39	0.37	7.56

Analysis of the climate indices in Table 11 reveals an increase in extreme temperatures between 1980-2000 and 2001-2020. The SU25 (days with Tmax ≥ 25°C), TX30 (≥ 30°C), TX35 (≥ 35°C), TX37 (≥ 37°C) and TX39 (≥ 39°C) indices all show a notable rise, with respective increases of 11.81%, 34.25%, 58.04%, 74.26% and 110.83%, confirming a gradual warming. The TR20 index (tropical nights with Tmin ≥ 20°C) also recorded a slight increase (+20.01%). The ID0 (frost days) and FD0 (frost nights) indices remain at zero, indicating a persistent absence of frost. The Kolmogorov-Smirnov (KS) test shows significant p-values for SU25, TX30, TX35 and TX37, suggesting a statistically significant change in temperature distribution over these periods, reinforcing the evidence of climate change marked by an increased frequency of extreme temperature days.

Table 12 shows trends in the WSDI, CSDI and GSL climate indices in terms of slope (days per decade), and their associated p-values. WSDI (Warm Spell Duration Index) shows an increase of 1.65 days per decade, but with a p-value of 0.387, indicating that this trend is not statistically significant. In contrast, CSDI (Cold Spell Duration Index) shows a decrease of 1.24 days per decade, with a p-value of -0.284, suggesting an inconsistency or error in the p-value. The GSL (Growing Season Length) index shows a notable increase of 10.9 days per decade, but its p-value of 0.473 shows that this trend is not significant. Overall, these results indicate a global warming trend, with an increase in the duration of warm periods (WSDI) and a reduction in cold periods (CSDI), although these trends are not statistically confirmed.

Table 11. Difference in average values of annual absolute-based (fixed) threshold temperature indices in Banjaluka in 2001–2020 in reference to 1980–2000.

Index	1980–2000	2001–2020	Difference (days)	Difference (%)	D [KS test]	p-value [KS test]
ID0	0.00	0.00	0.00	0.00	0.00	1.00
FD0	0.00	0.00	0.00	162.53	0.00	1.00
TR20	0.08	0.10	0.02	20.01	0.02	0.24
SU25	0.44	0.49	0.05	11.81	0.05	0.00
TX30	0.22	0.29	0.07	34.25	0.07	0.00
TX35	0.07	0.10	0.04	58.04	0.04	0.00
TX37	0.04	0.06	0.03	74.26	0.03	0.01
TX39	0.02	0.04	0.02	110.83	0.02	0.15

Table 12. Trends in annual duration-based air temperature indices in Bel-Ksiri in 1980−2024 (in days/10yr).

Index	Slope (days/10yr)	p-value
WSDI	1.65	0.38
CSDI	-1.24	-0.28
GSL	10.90	0.47

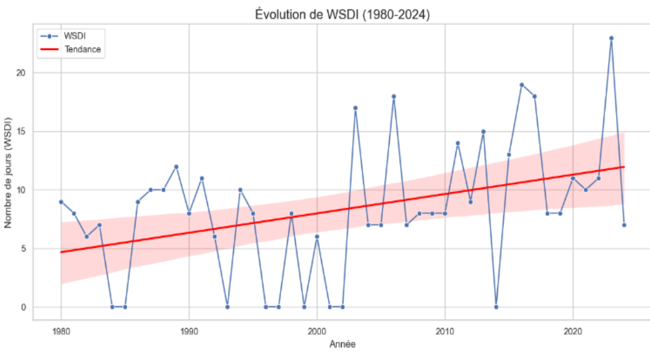

Figure 6. Deviations (in days) of the selected duration-based air temperature indices from 1980–2000 averages (the dashed line represents the trendline).

Analysis of the climatic indices in Table 13 between the periods 1980-2000 and 2001-2020 reveals marked changes. The WSDI (Warm Spell Duration Index) rose by 27.8%, from 612,590 to 783,135 days, indicating a significant increase in prolonged hot spells. In contrast, the CSDI (Cold Spell Duration Index) rose even more dramatically, by 150.3%, from 730 to 1,827 days, suggesting an intensification of cold spells despite global warming. As for the GSL (Growing Season Length), a slight decrease of 4.8% was observed, from 2,801,746 to 2,667,790 days, which could indicate an impact of climate change on the length of growing seasons. The Kolmogorov-Smirnov test (KS test) reveals statistically significant differences for all indices, with D values ranging from 0.0 to 0.8 and p-values of 0.0, confirming that these changes are not due to chance, but reflect marked climatic evolutions.

***Changes in mean precipitation*:** Seasonal and annual precipitation trends (table14) show significant variations. In winter, the slope is -10.6 mm/10 years (-1%), with a p-value of 0.388, indicating a negative but non-significant trend. In spring, a very slight increase of 0.6 mm/10 years (0.3%) is observed, with a p-value of 0.955, suggesting no marked trend. In summer, the trend is also negative (-0.8 mm/10 years, or -0.3%), with a p-value of 0.875, which does not allow us to conclude that there has been a significant change. In autumn, on the other hand, precipitation fell significantly, by -17.7 mm/10 years (-6.5%), with a p-value of 0.028, suggesting a statistically significant trend. For the year, an increase of 8.3 mm/10 years (3%) is observed, but the p-value of 0.239 indicates that this trend is not significant.

Table 14. Trends in precipitation in Bel-Ksiri in 1980–2024 (in mm/10yr and %/10yr).

Season	Slope (mm/10 years)	Slope (%)	p-value
Winter	-10.6	-1	0.388
Spring	0.6	0.3	0.955
Summer	-0.8	-0.3	0.875
Autumn	-17.7	-6.5	0.028
year	8.3	3	0.239

Precipitation analysis table 15 between the periods 1980-2000 and 2001-2020 shows a slight annual increase of 1.97% (from 447.05 mm to 455.87 mm), indicating overall stability. However, there are marked seasonal variations. Winter and spring saw a drop in precipitation of 6.66% and 2.09% respectively, while summer saw a more drastic decrease of 42.95%, from 11.69 mm to 6.67 mm, suggesting accentuated summer drying. Autumn, on the other hand, saw a significant increase of 23.92%, from 121.31 mm to 150.34 mm, which could reflect a redistribution of precipitation towards this season. The results of the Kolmogorov-Smirnov test show that the differences are not statistically significant (p-values > 0.05), suggesting that these variations could be due to natural variability rather than marked climate change.

***Changes in extreme precipitation indices*:** An analysis of trends and differences in precipitation indices at Bel-Ksiri between 1980 and 2024 reveals small, statistically insignificant variations overall. Annual trends in absolute and percentile indices (Table 16) show slight increases, as for PRCPTOT (+1.09 mm/10 years) and RX1day (+0.09 mm/10 years), but with high p-values (>0.05), indicating a lack of statistical significance. Similarly, a comparison of averages between 1980-2000 and 2001-2020 (Table 17) reveals minimal differences: PRCPTOT increased by 1.97%, while extreme indices such as RX1day (+4.8%) and RX5day (+0.91%) varied little. In contrast, the upper percentile indices (R99p and R95p) decreased slightly (-1.33% and -3.71% respectively), suggesting a possible reduction in the highest extreme precipitation. The Kolmogorov-Smirnov test (p-values ≈ 0.95) indicates that these differences are not statistically significant. Finally, trends in the fixed threshold

Table 13. Difference in average values of annual duration-based air temperature indices in Banjalu ka in 2001–2020in reference to 1980–2000.

Index	1980–2000	2001–2020	Difference (days)	Difference (%)	D [KS test]	p-value [KS test]
WSDI	612590.0	783135.0	170545.0	27.8	0.8	0.0
CSDI	730.0	1827.0	1097.0	150.3	0.1	0.0
GSL	2801746.0	2667790.0	-133956.0	-4.8	0.0	0.0

Table 15. Difference in average values of precipitation in Bel-Ksiri in 2001–2020 in reference to 1980–2000.

Season	1980–2000	2001–2020	Difference (days)	Difference (%)	D [KS test]	p-value [KS test]
Year	447.05	455.87	8.82	1.97	0.01	0.95
Winter	188.53	175.97	-12.56	-6.66	0.02	0.84
Spring	125.51	122.90	-2.62	-2.09	0.02	0.75
Summer	11.69	6.67	-5.02	-42.95	0.02	0.97
Autumn	121.31	150.34	29.02	23.92	0.02	0.95

and duration indices (Table 18) reveal little notable change, with variations close to zero and high p-values, confirming the absence of significant changes in the frequency of rainy days or dry and wet periods. These results suggest a relatively stable rainfall pattern at Bel-Ksiri over recent decades.

Table 16. Trends in annual absolute and percentile precipitation indices in Bel-Ksiri in 1980–2024 (mm/10yr, except for SDII mm/day/10yr).

Index	Slope (%)	p-value
PRCPTOT	1.09	0.51
SDII	0.008	0.41
RX1day	0.09	0.49
RX5day	0.06	0.81
R99p	0.04	0.33
R95p	0.01	0.54

Table 19 shows the evolution of precipitation indices between the periods 1980-2000 and 2001-2020. The average number of days with at least 1 mm of rain (R01mm) decreased slightly by 0.51%, while days with more than 10 mm of rain (R10mm) increased by 9.82%. On the other hand, days with more than 20 mm of rain (R20mm) decreased by 5.07%. Concerning dry and wet periods, the maximum duration of consecutive dry days (CDD) increased by 2%, indicating longer dry periods, while the maximum duration of consecutive wet days (CWD) rose by 4.55%, suggesting slightly longer rainy episodes. The Kolmogorov-Smirnov test (KS test) shows no significant difference between the index distributions of the two periods (D = 0.01, p-value = 0.95), suggesting that these variations are not statistically significant.

DISCUSSION

Morocco, like other West African countries, has experienced significant climate change since 1975 (Sebbar *et al.*, 2011), with marked variations in temperature and rainfall, leading to

Table 17. Difference in average values of annual absolute and percentile precipitation indices in Bel-Ksiri in 2001–2020 in reference to 1980–2000.

Index	1980–2000	2001–2020	Difference (days)	Difference (%)	D [KS test]	p-value [KS test]
PRCPTOT	447.05	455.87	8.82	1.97	0.01	0.95
SDII	4.44	4.58	0.14	3.12	0.01	0.95
RX1day	32.69	34.26	1.57	4.80	0.01	0.95
RX5day	120.80	121.90	1.10	0.91	0.01	0.95
R99p	75.00	74.00	-1.00	-1.33	0.01	0.95
R95p	377.00	363.00	-14.00	-3.71	0.01	0.95

*mm, except for SDII mm/day

Table 18. Trends in annual fixed-thresholds and duration precipitation indices in Bel-Ksiri in 1980–2024 (in days/10yr).

Index	Slope (days/10yr)	p-value
R01mm	0.00	0.99
R10mm	0.75	0.28
R20mm	0.18	0.54
CDD	-1.97	0.41
CWD	0.04	0.91

Table 19. Difference in average values of fixed-thresholds and duration precipitation indices in Bel-Ksiri in 2001–2020 in reference to 1980–2000.

Index	1980–2000	2001–2020	Difference (days)	Difference (%)	D [KS test]	p-value [KS test]
R01mm	60.76	60.45	-0.31	-0.51	0.01	0.95
R10mm	13.48	14.80	1.32	9.82	0.01	0.95
R20mm	3.48	3.30	-0.18	-5.07	0.01	0.95
CDD	100.00	102.00	2.00	2.00	0.01	0.95
CWD	22.00	23.00	1.00	4.55	0.01	0.95

environmental, economic and social transformations. During this period, Morocco recorded a sharp drop in rainfall, coinciding with the 1980-1981, 1981-1982, 1982-1983 and 1983-1984 seasons (Maurer, 1996), marked by a succession of drought years that had a considerable impact on water resources. These dry years severely affected the country's water reserves, reducing stocks in dams and rivers. At the same time, this drop in precipitation has been accompanied by a significant rise in temperatures, which has contributed to an increase in the rate of evaporation from dams and lakes. This rise in temperature has also significantly increased plant water requirements, which has had a major impact on agricultural and pastoral activities, while increasing pressure on Morocco's water resources. As a result, the climate challenge has become increasingly complex in the face of these rapid changes. The results obtained in this study on the analysis of temperature and precipitation trends at the Mechraa Bel Ksiri meteorological station, located in the Gharb plain, clearly demonstrate that the study area is undergoing climate change, as evidenced by the climatic indices. The study of air temperature through these indices confirmed an increase in temperatures in the study area, corroborating the findings of other research conducted in Morocco (Driouech , 2010) and in other parts of the world (Popov *et al.*, 2023). All studies analyzing precipitation in Morocco have clearly shown a decline in rainfall amounts, as is the case for the Fès-Meknès region, where a significant drop has been recorded, varying between 10 mm and 20 mm per decade (Kessabi *et al.*, 2023). This drop in rainfall will have a major impact on agricultural activities on the Gharb plain (El Karfa *et al.*, 2023b), both those directly dependent on rainfall and irrigated agriculture, as it will negatively influence river flow), thus increasing pressure on surface water resources (El Karfa and Karkouri, 2024; El Karfa *et al.*, 2024), of which rainfall is the main source. This change in rainfall distribution will coincide with global warming, which will manifest itself on a seasonal and annual scale.

Recently, the recurrence of drought years has become more marked, a phenomenon observed through several studies, both in the study area (El Karfa *et al.*, 2023a) and in other regions (Karambiri, 2024). This situation will increase pressure on water resources, especially as the study area is part of the Sebou basin, which is rich in water resources. Faced with the deficit in neighboring basins, notably the Bouregreg basin, a hydraulic highway has been set up to transfer part of the water from downstream in the Sebou basin to the latter, to supply the population with drinking water.

***Conclusion*:** This study enabled us to determine temperature and precipitation trends, as well as to identify deviations and relative changes between the two study periods in the Central Gharb plain. This plain has great agricultural potential, which means that the results of this study must be taken into account. It is important to note that the acceleration of climate change began in Morocco in the late 1970s, when a decrease in average rainfall and an increase in temperature was observed. The study's adoption of several climate indices, developed by climate experts to determine temperature and precipitation trends, is of key importance to understanding the impact of climate change on the environment and society. These indices are essential tools for analyzing long-term changes and providing accurate perspectives on the region's climatic future. Through these analyses, it is possible to identify periods marked by increases in temperature or decreases in precipitation, helping to predict the consequences of these changes on agriculture, water and ecosystems. This will enable effective public policies to be put in place that consider the preservation of water resources, now a major challenge in the face of climate change. For example, it would be wise to orient agricultural practices towards the adoption of low-water or drought-resistant crops, which will help ensure the sustainability of agricultural production in the face of climate change. In addition, it will help improve water management strategies by providing accurate data to guide irrigation operations and use water more efficiently. Raising society's awareness is also a crucial aspect in this context. Education on the importance of rationalizing the use of water resources and the need to preserve them in a changing climate environment will have a major impact on the behavior of individuals and communities. Educational institutions, the media and community organizations can play a key role in spreading this culture and reinforcing sustainability practices.

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***SDGs addressed*:** Climate Action, Zero Hunger, Clean Water and Sanitation.

***Policy referred*:** Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) and national climate adaptation and mitigation frameworks aligned with IPCC guidelines.

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REFERENCES

Abera, W., G. Formetta, L. Brocca and R. Rigon. 2017. Modeling the water budget of the Upper Blue Nile basin using the JGrass-NewAge model system and satellite data. Hydrology and Earth System Sciences 21:3145-3165.

Alexander, L.V. 2016. Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. Weather and Climate Extremes 11:4-16.

Bouaiche, A., N. Chair, M-S. Karrouk and C. Majda. 2021. Tendances et variabilité des pluies extrêmes au Maroc septentrional (1976-2016): Analyse par des indices climatiques calculés. Actes du XXXIV ème Colloque international de l'AIC. Mohammedia – Maroc.

Bourgault, P., D. Huard, T. Smith, T. Logan, A. Aoun, J. Lavoie, É. Dupuis, G. Rondeau-Genesse, R. Alegre, C. Barnes, A. Beaupré-Laperrière, S. Biner, D. Caron, C. Ehbrecht, J. Fyke, T. Keel, M.-P. Labonté, L. Lierhammer, J.-F. Low, and C. Whelan. 2023. xclim: xarray-based climate data analytics. Journal of Open Source Software 8:5415. https://doi.org/10.21105/joss.05415.

Driouech, F. 2010. Distribution Des Precipitations Hivernales Sur Le Maroc Dans Le Cadre D'un Changement Climatique: Descente D'echelle Et Incertitudes [These de Doctorat De L'universite De Toulouse].

Driouech, F., S. Ben Rached, and T. Al Hairech. 2013. Variabilité et changement climatiques dans les pays d'Afrique du Nord. In M. V. K. Sivakumar, R. L. R. Selvaraju, and I. Hamdan (eds.), Climate Change and Food Security in West Asia and North Africa, pp. XX-XX. Springer.

Dunn, R.J.H. and C.P. Morice. 2022. On the effect of reference periods on trends in percentile-based extreme temperature indices. Environmental Research Letters 17:034026. https://doi.org/10.1088/1748-9326/ac52c8.

Dunn, R.J.H., L.V. Alexander, M.G. Donat, X. Zhang, M. Bador, N. Herold, T. Lippmann, R. Allan, E. Aguilar, A.A. Barry, M. Brunet, J. Caesar, G. Chagnaud, V. Cheng, T. Cinco, I. Durre, R. de Guzman, T. Mar Htay and M.N.A. B.H. Yussof. 2020. Development of an updated global land in situ-based data set of temperature and precipitation extremes: HadEX3. Journal of Geophysical Research: Atmospheres vol. 125. https://doi.org/10.1029/2019JD032263.

Expert Team on Climate Change Detection and Indices. 2009. Climate change indices: definitions of the 27 Core Indices. Retrieved from http://etccdi.pacificclimate.org/list_27_indices.shtml

El Karfa, D., J. Al Karkouri, M. Batchi, and H. Boudine. 2024. Assessing the influence of the Al Wahda dam commissioning on flood flows and low water levels in the Gharb plain, Morocco. Journal of the Geographical Institute "Jovan Cvijić" SASA 74:273-280. https://doi.org/10.2298/ijgi240122010e.

El Karfa, D. and J. Al Karkouri. 2024. Les ressources en eau superficielles et souterraines dans la plaine du Gharb centrale: Cas de la commune territoriale d'ERMILATE, Province de Sidi Kacem. Territoires, Environnement et Développement (TED) 3:47-55. https://doi.org/10.34874/IMIST.PRSM/ted-v3i1.42860.

El Karfa, D., J.A. Karkouri, M. Batchi, and H. Boudine. 2023a. Impacts of rainfall variability in Gharb plain: Morocco. Bulletin of the Serbian Geographical Society 103:293-308. https://doi.org/10.2298/gsgd2302293e.

El Karfa, D., J.A. Karkouri, M. Batchi, and H. Boudine. 2023b. Assessing the influence of flow variability on irrigated agriculture in the Central Gharb Plain, Morocco. Journal of Global Innovations in Agricultural Sciences 11:507-513. https://doi.org/10.22194/JGIAS/23.1210.

Hakam, O., A. Baali, Y. Ait Brahim, T. El Kamel and K. Azennoud. 2022. Regional and global teleconnections patterns governing rainfall in the Western Mediterranean: Case of the Lower Sebou Basin, North-West Morocco. Modeling Earth Systems and Environment 8:5107-5128. https://doi.org/10.1007/s40808-022-01425-3.

Hakam, O., A. Baali, K. Azennoud, T. El Kamel, Y. Ait Brahim and Y. Ahouach. 2022. Spatiotemporal evolution of droughts and their teleconnections with large-scale climatic indices in the Lower Sebou Basin in northwestern Morocco. Acta Geographica Slovenica 62:23-47. https://doi.org/10.3986/AGS.10508.

Intergovernmental Panel on Climate Change. 2021. Climate Change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change. cambridge university press. https://doi.org/10.1017/9781009157896.

Jasman, S., M. Juharsah, A.S. Sukri, E. Ngii, and Hasddin. 2023. Model of the linkage between land cover changes to water discharge and food productivity: The case of the Konaweha watershed in Indonesia. Journal of the Geographical Institute "Jovan Cvijić" SASA 73:169-185. https://doi.org/10.2298/IJGI2302169M.

Karambiri, B.L.C.N. 2024. Variability of climatic parameters in Tiefora, Burkina Faso: Scientific aspects and farmers'

perceptions. Glasnik Srpskog geografskog društva 104:245-256.

Kessabi, R., M. Hanchane, T. Caloiero, G. Pellicone, R. Addou, and N.Y. Krakauer. 2023. Analyzing spatial trends of precipitation using gridded data in the Fez-Meknes region, Morocco. Hydrology 10:37.

Kliment, C.R., J.M. Englert, L.P. Crum, and T.D. Oury. 2011. A novel method for accurate collagen and biochemical assessment of pulmonary tissue utilizing one animal. International Journal of Clinical and Experimental Pathology 4:349.

Le Coz, J. 1964. Le Gharb, Fellahs et Colons. Centre universitaire de la recherche scientifique.

Maurer, G. 1996. L'homme et les montagnes atlasiques au Maghreb. Annales de géographie 587:47-72.

Phumkokrux, N. 2023. Trend analysis and prediction of temperature change in continental thailand. bulletin of the serbian geographical society 103:65-86. https://doi.org/10.2298/gsgd2301065p

Popov, T., S. Gnjato, G. Trbić and M. Ivanišević. 2023. Changes in air temperature and precipitation in Banjaluka in 1961-2022. Glasnik Srpskog geografskog društva 103:231-254.

Sebbar, A., W. Badri, H. Fougrach, M. Hsaine, and A. Saloui. 2011. Etude de la variabilité du régime pluviométrique au Maroc septentrional (1935-2004). Sécheresse, 22:139-148. https://www.researchgate.net/publication/251559546_Etude_de_la_variabilite_du_regime_pluviometrique_au_Maroc_septentrional_1935-2004

Schilling, J., E. Hertig, Y. Tramblay and J. Scheffran. 2020. Climate change vulnerability, water resources, and social implications in North Africa. Regional Environmental Change 20:15.

Valjarević, A., M. Milanović, I. Gultepe, D. Filipović and T. Lukić. 2022. Updated Trewartha climate classification with four climate change scenarios. The Geographical Journal 188:506-517. https://doi.org/10.1111/geoj.12458.

Wilhelm, B., W. Rapuc, B. Amann, F.S. Anselmetti, F. Arnaud, J. Blanchet, A. Brauer, M. Czymzik, C. Giguet-Covex, A. Gilli, L. Glur, M. Grosjean, R. Irmler, M. Nicolle, P. Sabatier, T. Swierczynski and S.B. Wirth. 2022. Impact of warmer climate periods on flood hazard in the European Alps. Nature Geoscience 15:118-123. https://doi.org/10.1038/s41561-021-00878-y.

World Meteorological Organization. 2023. L'Afrique pâtit de manière disproportionnée du changement climatique et des coûts de l’adaptation. Retrieved from https://wmo.int/fr/news/media-centre.

Zhang, P., G. Ren, Y. Xu, X.L. Wang, Y. Qin, X. Sun and Y. Ren. 2019. Observed changes in extreme temperature over the global land based on a newly developed station daily dataset. Journal of Climate 32:8489-8509. https://doi.org/10.1175/JCLI-D-18-0733.1.

Zhang, Y., Q. Li, Y. Ge, X. Du and H. Wang. 2022. Growing prevalence of heat over cold extremes with overall milder extremes and multiple successive events. Communications Earth & Environment 3:73. https://doi.org/10.1038/s43247-022-00404-x.

Zhao, Z., W. Wang, Y. Wu, M. Xu, X. Huang and Y. Ma. 2015. Leaf physiological responses of mature pear trees to regulated deficit irrigation in field conditions under desert climate. Scientia Horticulturae 187:122-130. https://doi.org/10.1016/j.scienta.2015.03.009.